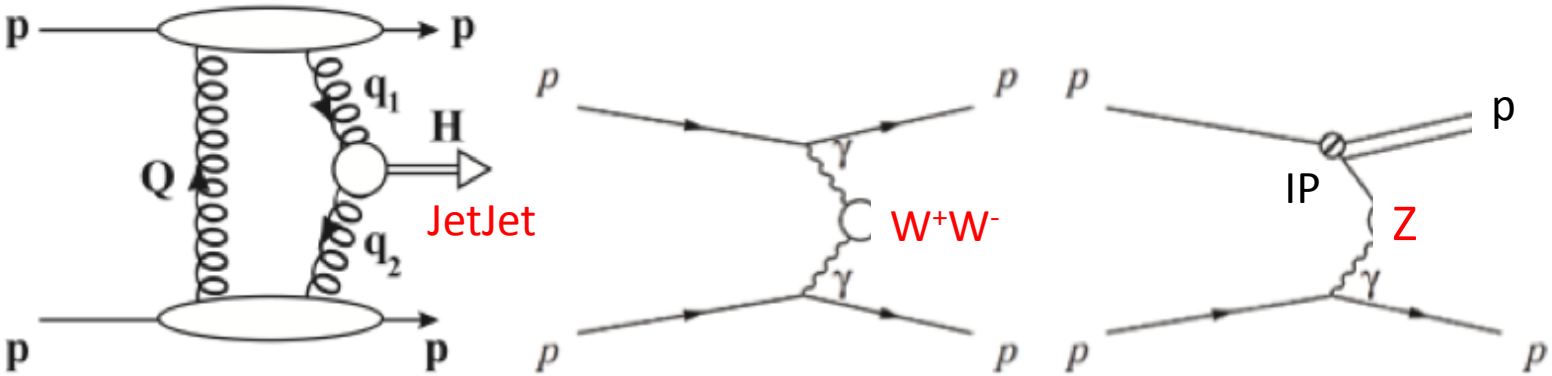
T979 QUARTIC Timing detectors for HPS240

M.Albrow, A.Ronzhin, S.Malik, Sergey Los, A.Zatserklyanyi, E.Ramberg, Heejong Kim

New physics channels for CMS (and ATLAS):

p + p → p + (X = H, Z, W+W-, Jet+Jet) + p EXCLUSIVE

Examples:



Propose to: add very forward (240m, later 420m) proton detectors (see both protons)

Measure their tracks precisely : LHC as spectrometer (HPS = High Precision Spectrometer)

Combined with central CMS detectors → Central mass, Spin J, CP, couplings.

Need to run at L = 10^{34} $cm^{-2}s^{-1}$ with Δt = 25ns i.e. Pile-Up <N/X> = 25

Two protons from different pp collisions is a major background.

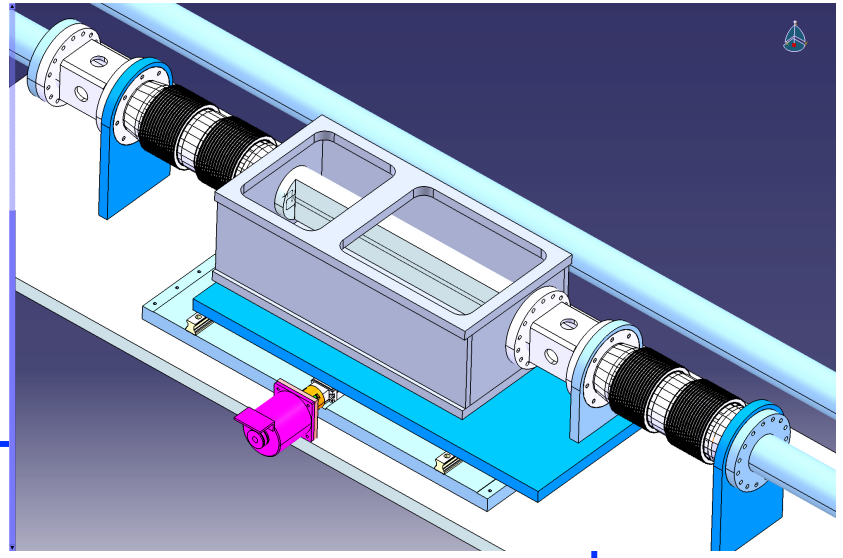
Kinematic constraints: 4-momentum conservation because exclusive, but not enough .

Time difference Δt between protons crucial: σ(Δt) ~ 10ps → $\sigma(z_{pp})$ = 2.1 mm

Proposed by M.A. & A.Rostovtev, arXiv:hep-ph/0009336 (2009)

Status: We are finalizing a Technical Proposal to CMS to install moving pipe sections at +/- 240 m in Long Shutdown 1 (LS1) by mid 2014. Demonstrate timing detectors

Preliminary design of “Moving beam pipe” (better than “Roman pots”)

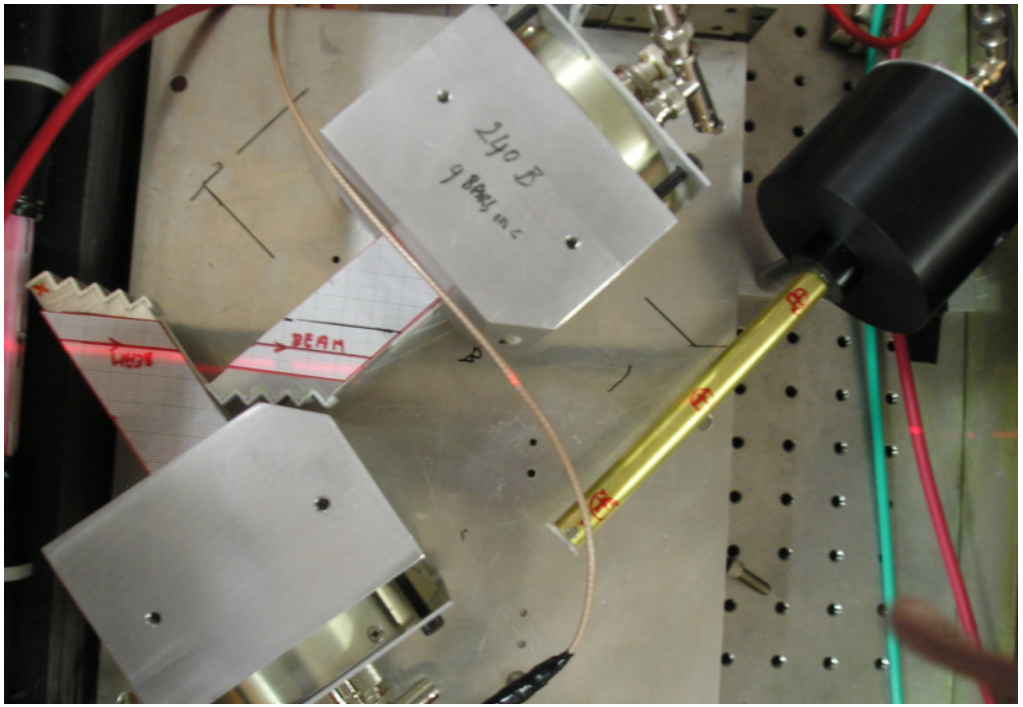


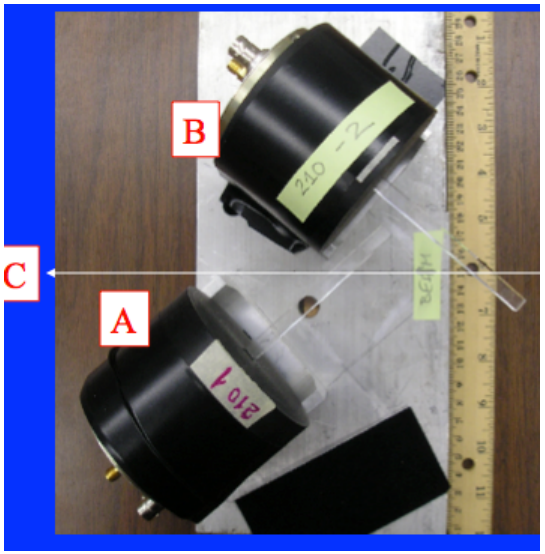
Stringent requirements on timing system, needs novel solutions:

Requirements of timing system:
Time resolution ~ 10 ps
Area ~ 8 mm (V) x 20 mm (H)
Segmentation for > 1 proton/bunch
Edgeless, active to ~ 200 µm from pipe
Radiation hard, ~ $10^{12}/cm^2$
Lifetime > ~ 1 year at LHC at 10^{34}
Rate: 25 ns sensitivity
Reference time system (“clock”) with < few ps jitter at stations 500m apart

At Fermilab we built and tested (14-18.2.2012) in beam a **QUARTIC** prototype, solving technical issues and achieving 16 ps in a 4-bar (in z) module with 3mm x 3mm elements.
It uses quartz (fused silica) L-shaped bars: 30 (40) mm radiator bar and 40 mm light guide bar read by a silicon photomultiplier (SiPM).

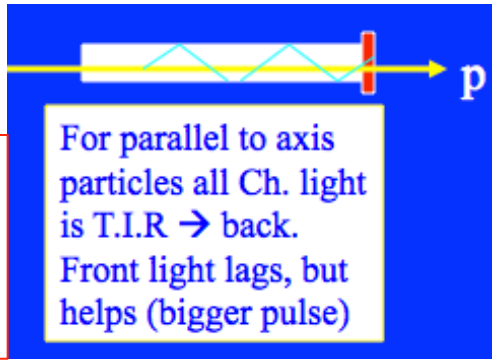
2010-2011 Series of studies with “angled-bar” QUARTIC;:
Bars at $\theta_{ch} = 48^{o}$ so wavefront is parallel to MCP photocathode
Several bars onto one MCP (PHOTEK 240, $20K!) or multi-anode MCP.



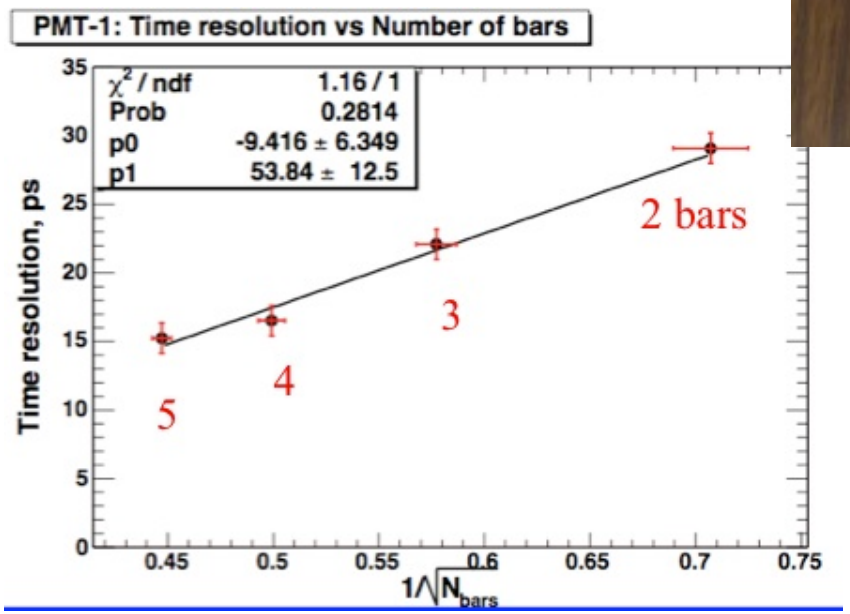


Achieved σ(t) = 16ps/unit ➔ 11.3 ps in combination.
But: MCP-PMT have limited photocathode lifetime
(only weeks/months close to LHC beam)
and are expensive.
Segmentation limited.

Consider SiPMs at end of quartz bar:
Cheap, no lifetime issue but rad soft.
Achieved 20ps(best) 30ps(typical)...
But cannot have SiPM close to beam!

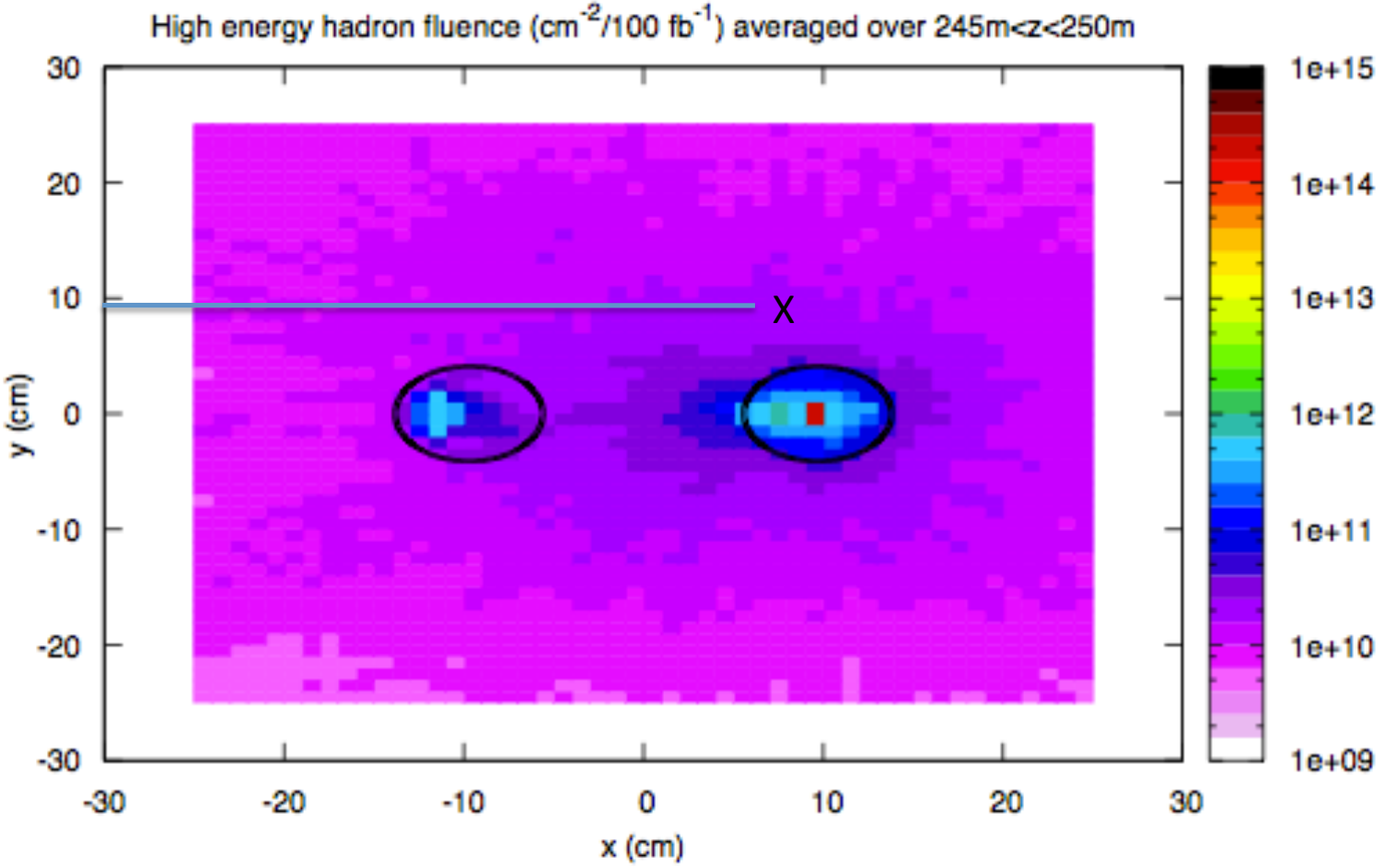


Angled-bar quartic with MCP- PMT240

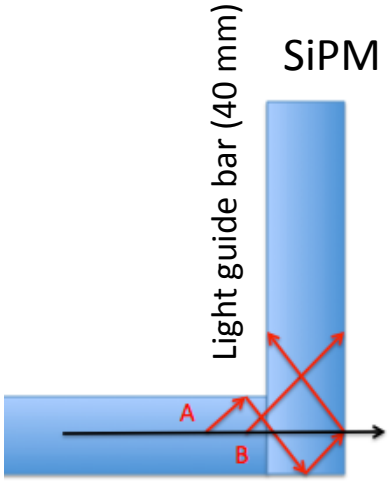


From Luigio Esposito:

Moving SiPMs out of beam plane is important to minimize radiation.



Hadron fluences fall fast with y: few 10^{10} / cm^2 at y = 10cm in 100 fb-1
Can also shield at that position



L-BAR QUARTIC: LBQ

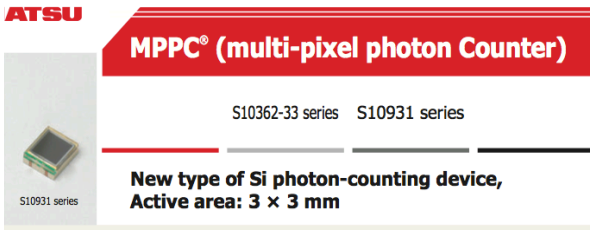


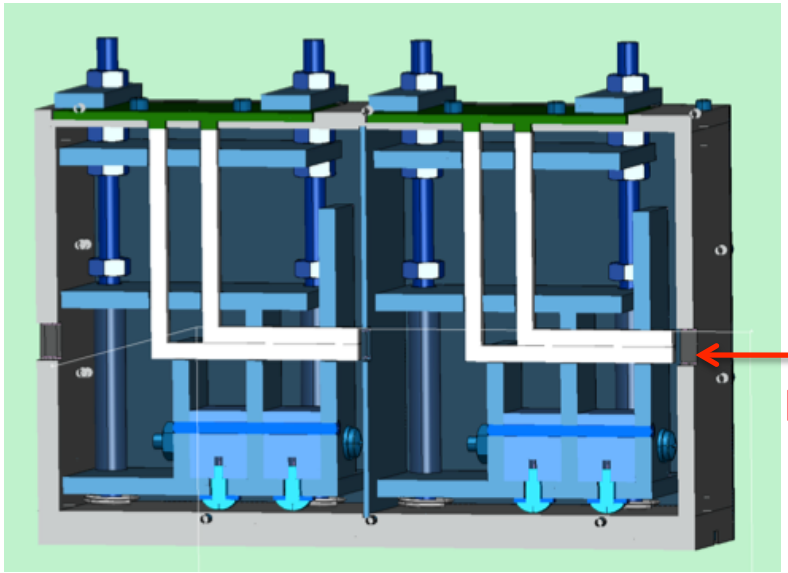
Figure 2
Back, and front view of the board with parts, light gasket, and light patch installed

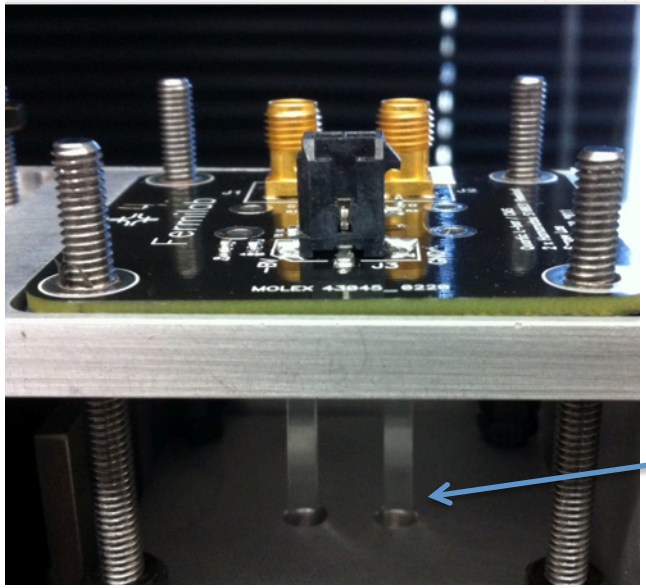
Sergey Los designed the SiPM board

Principle: All Cherenkov light is totally internally reflected to back of radiator bar. ~ 50% goes promptly up LG, rest after more reflactions.

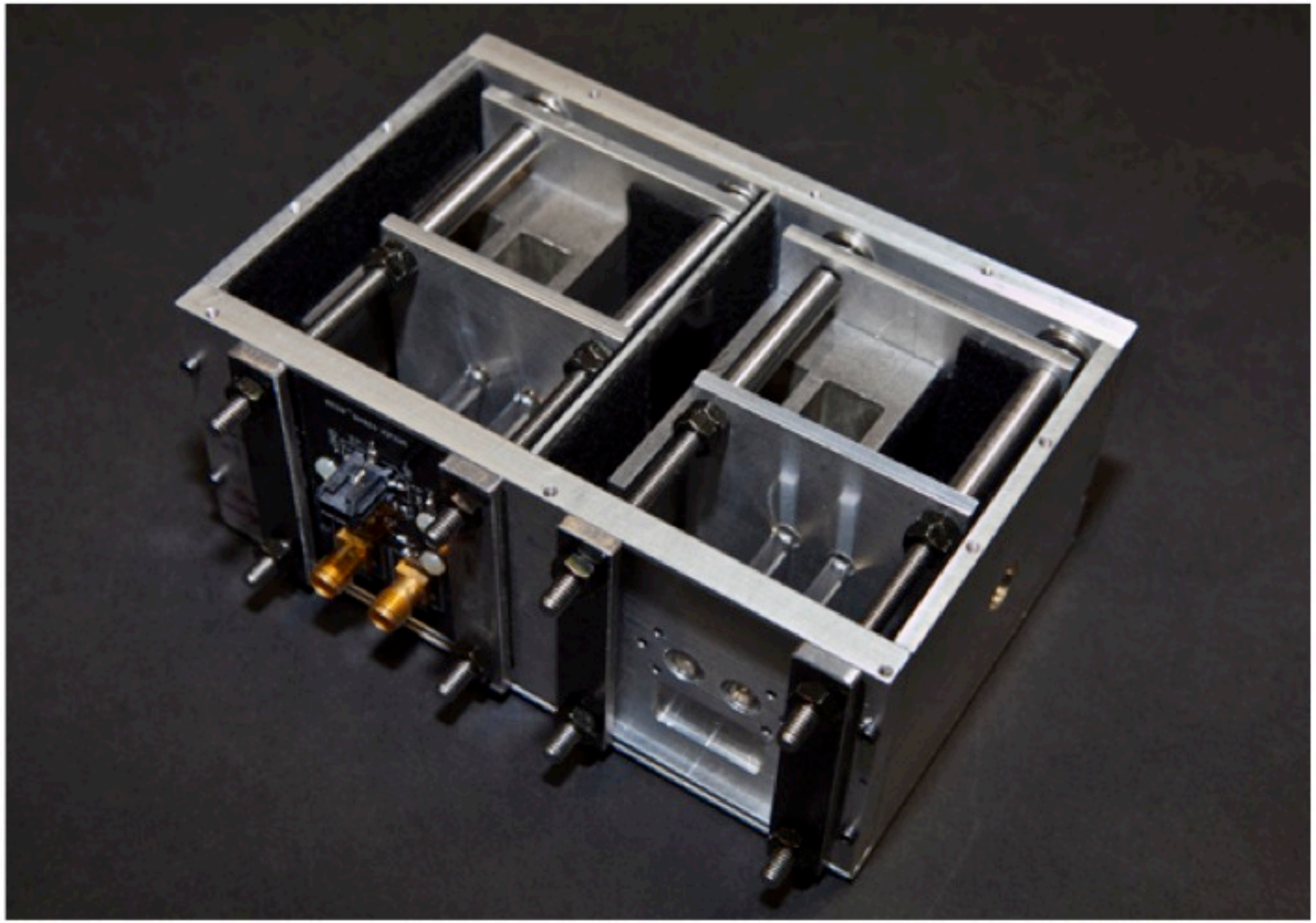
Maintain TIR: nothing touches surfaces, except minimal at corners. Bars separated by fine wire (100 um) ... keep TIR.

Design of test module (made 2)



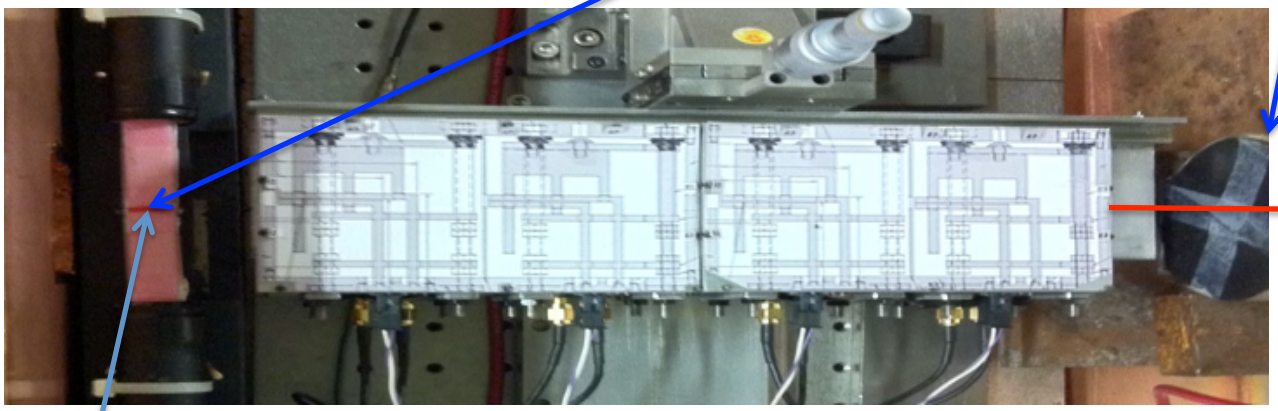


Thanks: John Rauch, Steve Hentschel (design)
Dave Erickson & w/shop for construction



L-BAR QUARTIC test module (1 of 2), Feb 2012 at Fermi test beam

Four units in test beam, 2mm x 2mm trigger counter + 40mm MCPPMT reference (10 ps)



proton

trigger counter

(Drawings glued on boxes for alignment only)
Two boxes can be slid apart in z

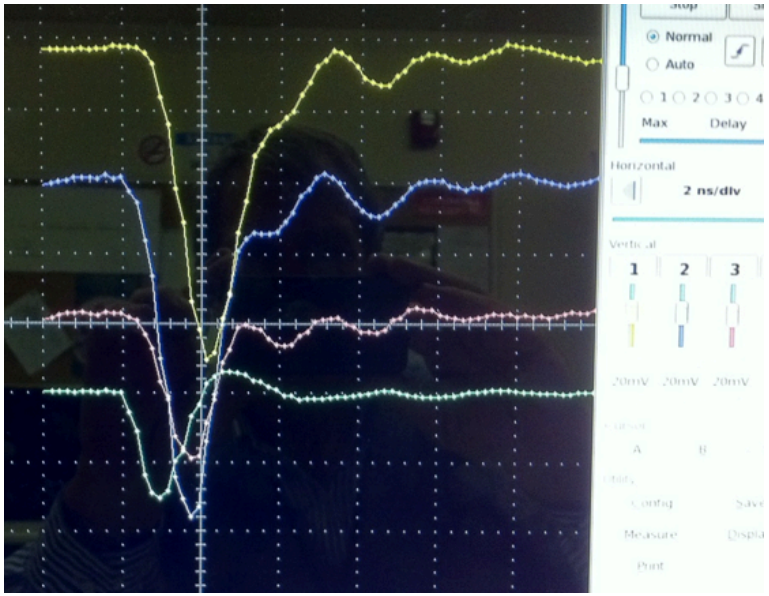
70V on SiPMs,
Clip signals (90pF) & x 20 preamp.

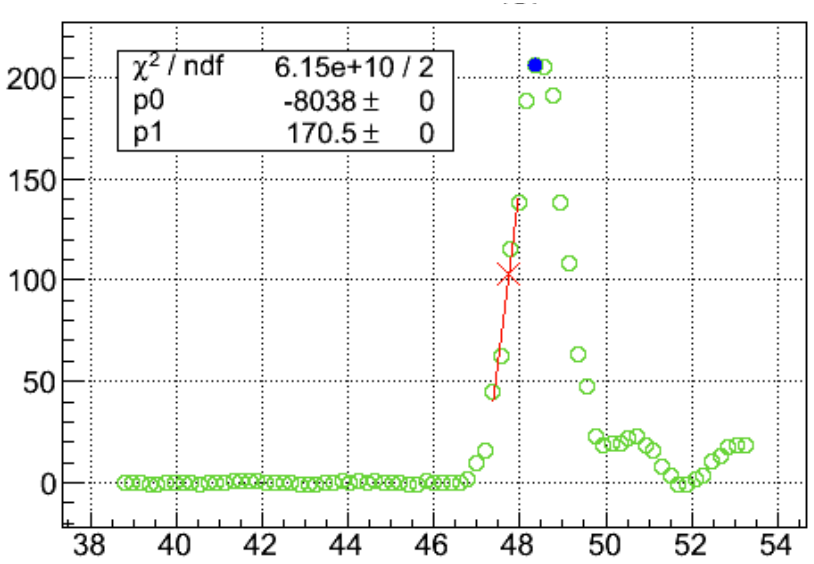
→ DRS4 5 GHz waveform digitiser
Read 8 traces (200 ps/point)
20 mV/div. & 2 ns/div

(Anatoly Ronzhin's talk)

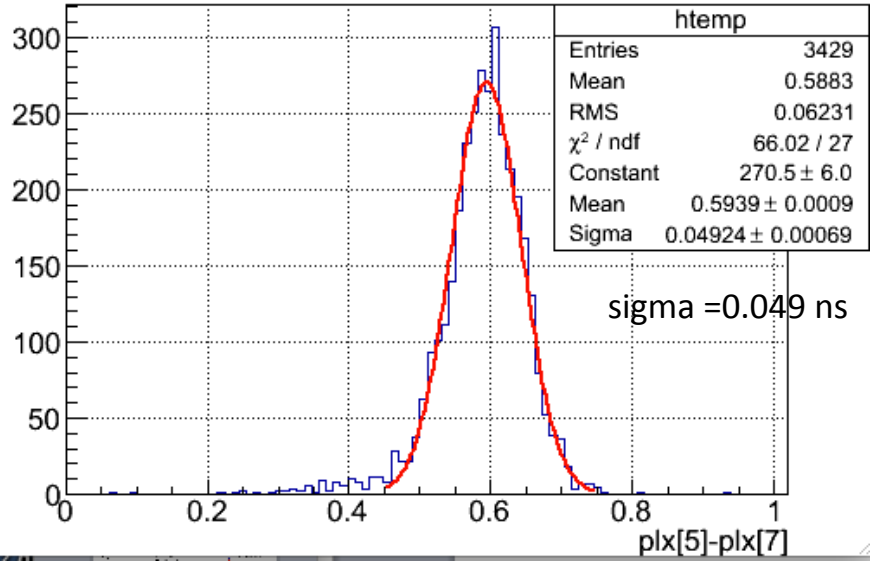
One event:
3 bars in line

MCPPMT ref





(Andriy Zatserklyani did analysis)
Preliminary fit for t:
50% point, interpolate -2 & +2 points
No time slewing corrections yet (later)



sigma =0.049 ns

Bar 1S – Ref, σ = 49 ps.
Bar intrinsic 42 ps
Before time-slewing corrections

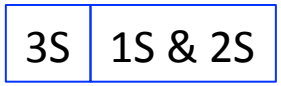
Summary of LBQ runs (all 5000 events except 30, 2000):

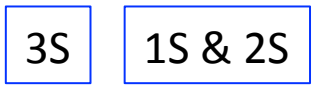
Run(s)	Bars in line	DRS4-1	DRS4-2
No Cap.			
1+2+3+4+5	Short	1L 2L 3L	**1S 2S 3S**
6+7+8+9	Long	**1L 2L 3L**	1S 2S 3S
With Cap:			
20+21	Long (?)	**1L 2L 3L**	**4L** 1S 2S
24+25	Short	1L 2L **3S**	**4S 1S 2S**
26+27	Short+30mm	1L 2L **3S**	**4S 1S 2S**
28+29	Light guides	**1L 2L 3S**	**4S 1S 2S**
30	48deg	1L **2L** 3S	4S 1S **2S**

Nice check of calibration

Separate boxes by 3 cm

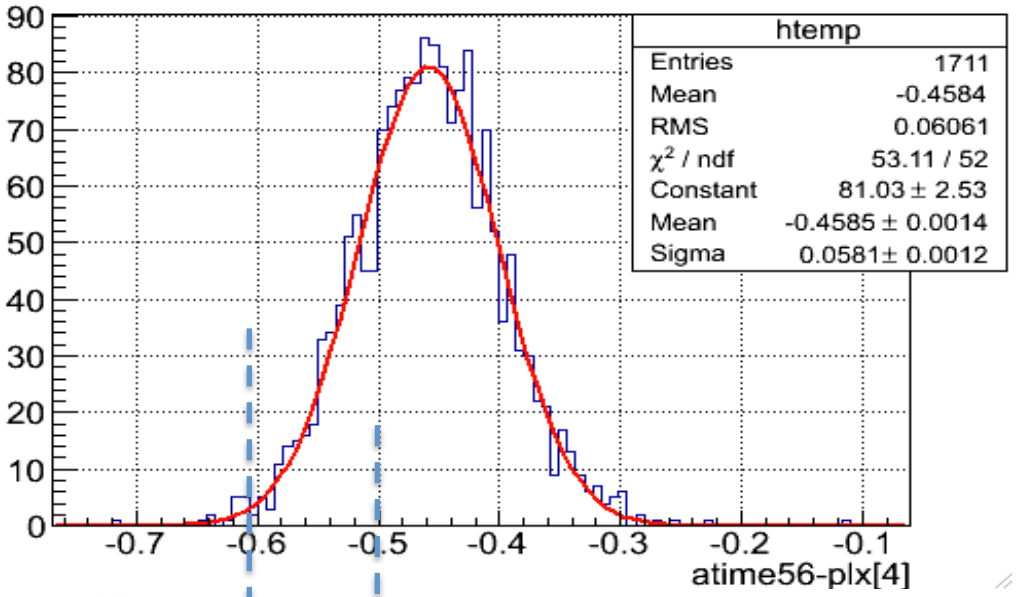
Δt = 100 ps = peak shift

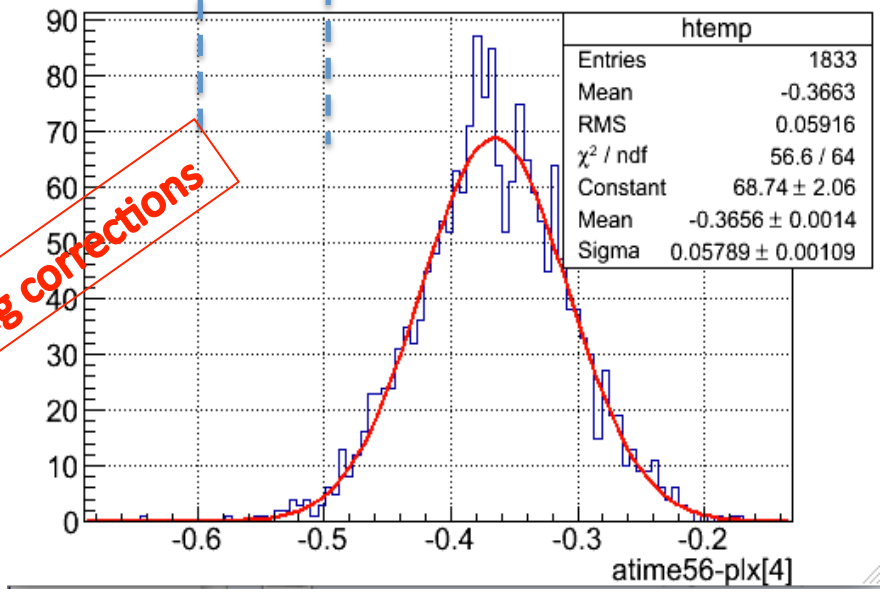




BOX 1 BOX 2

Measure the speed of protons (c) over 3 cm!





Before time slewing corrections

With time-slewing (PH) corrections. Tried full waveform fit, little difference.

Results of Gaussian fits to time differences between channels:
S = short (30mm) bars (1 – 4). X = PMT240 reference

L-bar matrix fits Run 24

	DRS41-2	DRS$1-3	DRS41-4	DRS42-1	DRS42-2	DRS4-3	DRS42-4
DRS41-2	x						
DRS41-3		x	3S-X 40.1ps	3S-4S 50.7ps	3S-1S 51.0ps	3S-2S 54.3ps	
DRS41-4			x				
DRS42-1				x	4S-1S 43.9ps	4S-2S 43.4ps	4S-X 35.3ps
DRS42-2					x	1S-2S 45.2ps	1S-X 34.9ps
DRS42-3						x	2S-X 39.6ps
DRS42-4							x

Between 2 DRS4 Boxes

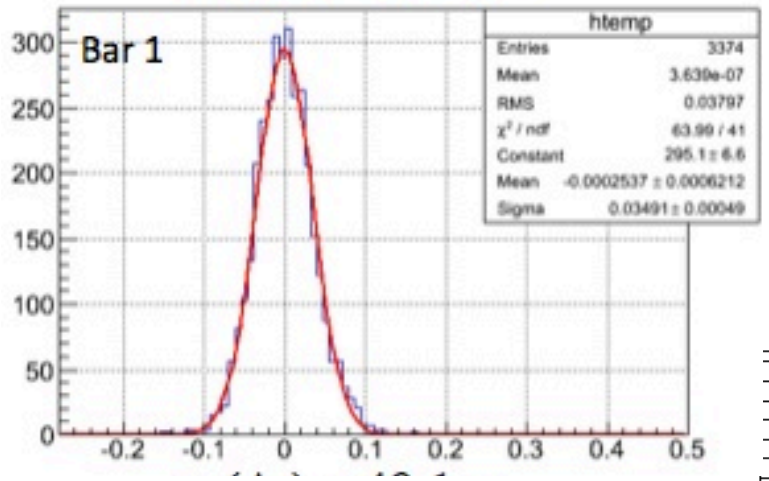
In same DRS4 Box

All 4 bars same resolution: <RMS> = 37.5 ps (spread σ = 2.4ps) with PMT240
Unfold PMT240 (10 ps) : 36.1 ps

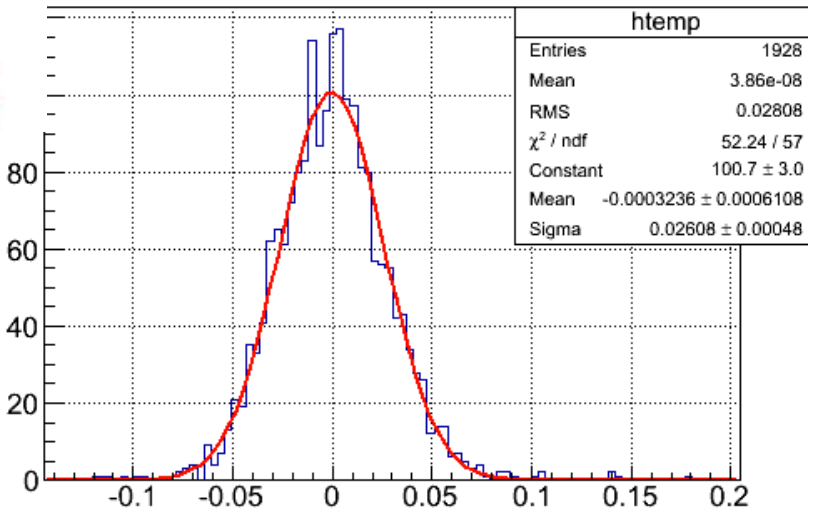
Bar-Bar (in same box) : <RMS> = 44.1ps (spread σ = 0.8ps)
Divide by √2 : 31.2ps

(Would agree if σ (PMT240) = 20 ps.)
If just average: 33.6ps each bar: QUARTIC QUARTET σ = 16.8 ps.

$\sigma(\Delta t) = 34.9$ ps



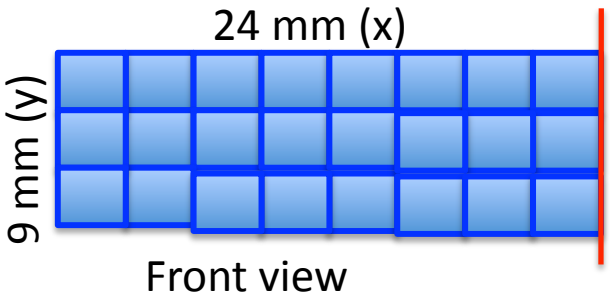
1 Lbar vs PMT240
(after time slewing corr)
→ 32 ps intrinsic
→ 16 ps 4 in-line



[3-bar combo] – PMT240: σ = 26.1ps --> 22.6ps for 4 bar
→σ(4-bar) = 16.9ps after unfolding PMT240 and electronics

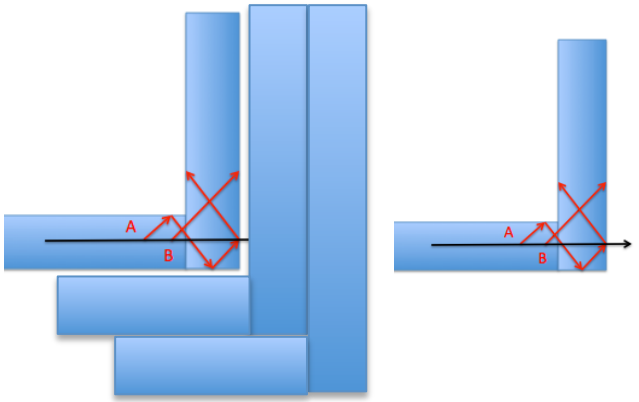
QUARTICs for HPS240: topology

Baseline design. Now know how to make, but needs full design (2 bars → 24 bars)
Flexibility allowed in bar arrangements (e.g. smaller cells close to beam)

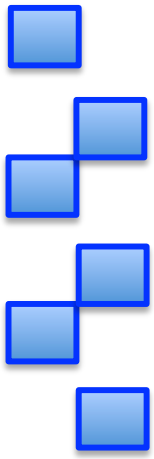


Thin wall only for light tightness, spaced off bars by ~ 100 um

Nested L-bars:
Bad sketch but principle works



Top view SiPMs
Spaced out & staggered thus ...

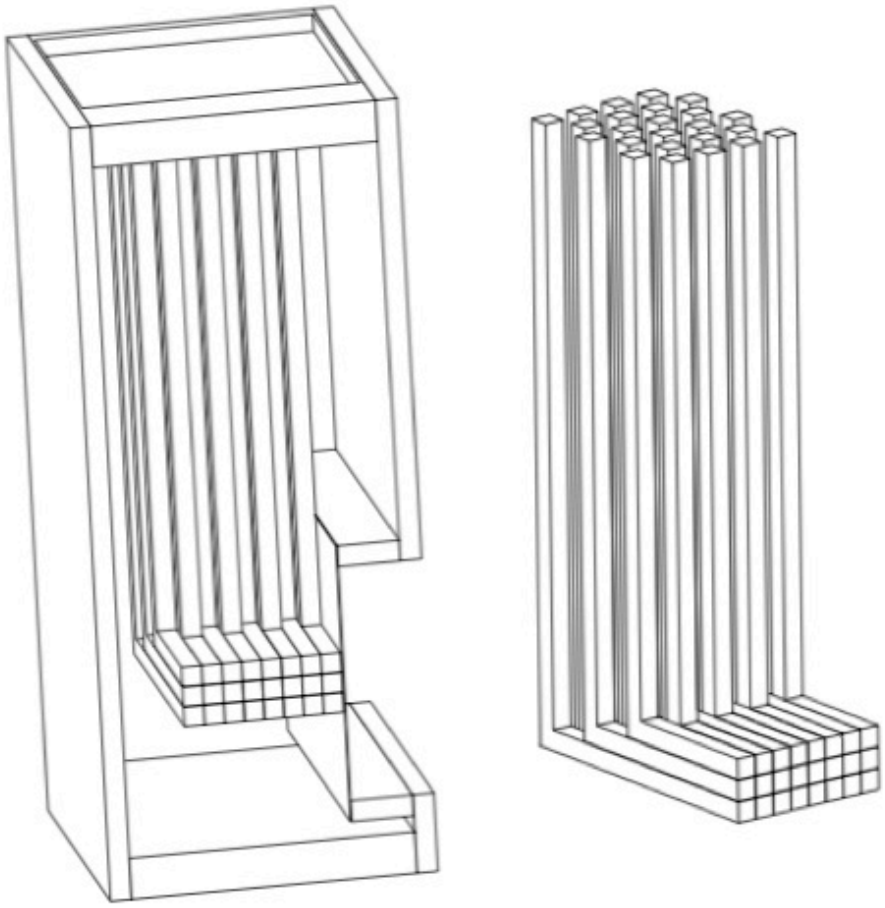


These are at height ~ 8-10 cm above beam height (tbd, radiation shielding needs)

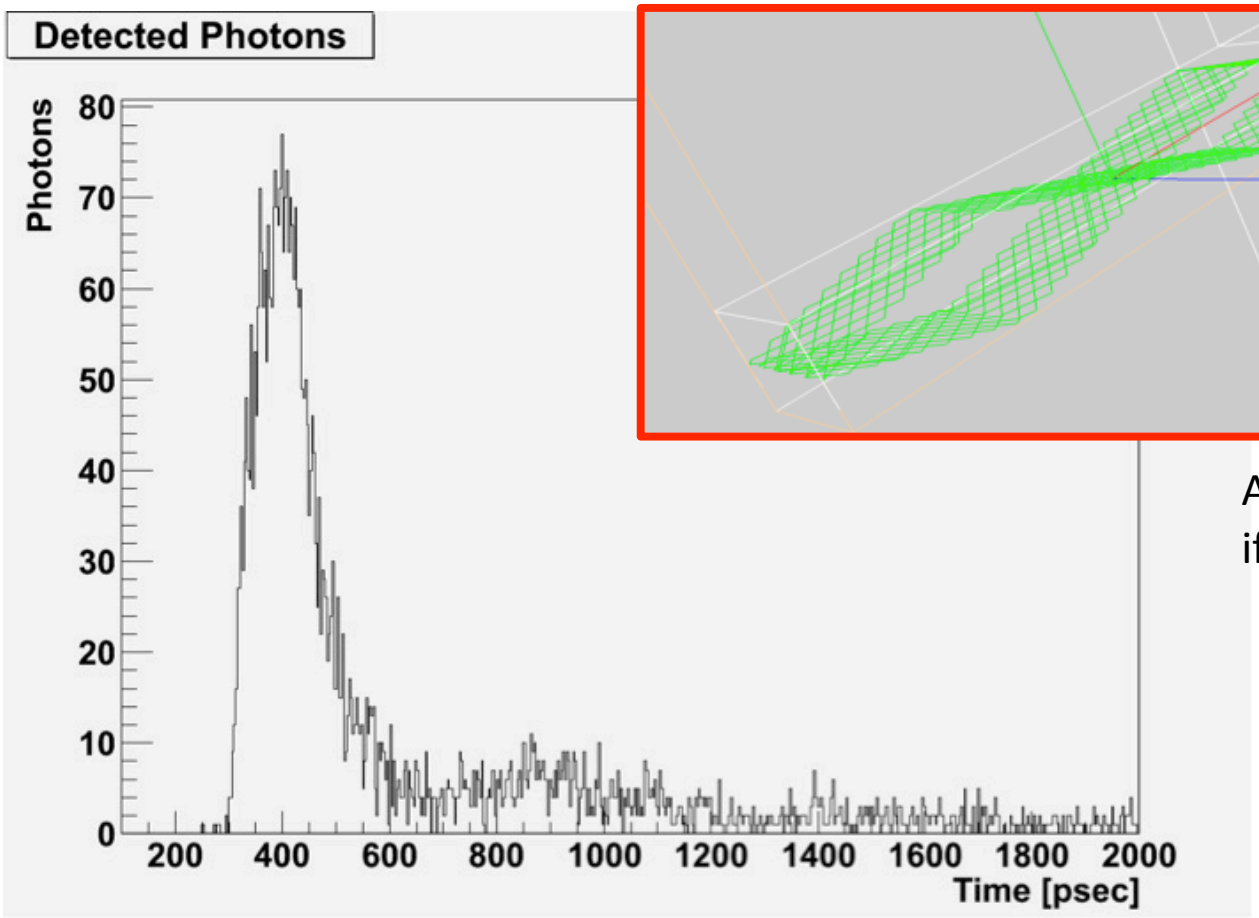
Protons can go through LGs of a different layer.
Measured it, ~ 10% of light
We know where tracks go

For CMS-HPS:
24 channels per module, 4 modules per arm = 96 SiPMs
Both arms 192 SiPMs, readout channels
"Timetrack" = Could have smaller cells, staggered, more layers ...

Basic design of 24 channel 3mm x 3mm module for HPS @ CMS
SiPMs are 80-100 mm above beam plane (low radn region and shieldable)



GEANT Simulation of LBarQuartic (Vladimir Samoylenko):
Wavelength dependent emission, absorption, detection.
Full time simulation up to photoelectron emission.



All photons trapped
if perfect reflection!

For optimization of detector design.
100% TIR is very important (100 reflections!). Being studied.

L-Bar quartic as beam halo monitor?

Area 1 mm x 1 mm → few mm x few mm
Fast and high rate
Radiation hard (near beam)
(quasi) Directional

Could have a ring around the beam with tunable radius

SUMMARY:

We have solved most technical issues to make a QUARTIC QUARTET (4-in-line)
with 24 (say) x,y elements per module
Beam tests demonstrate σ(t) = ~ 32ps/bar = 16ps/4-bar set.
(In combination with GASTOF, OK, but would like better of course!)
Need full design, costing and prototyping module for LHC.

Improvements are possible, at least:

SiPM borrowed from HO upgrade, and not the best for timing (pixel size).
SiPM UV sensitivity may be improved.
Is fused silica the best? Saphire?
Radiator bar length may not be optimum (30 mm better than 40 mm) SIMs GEANT!
Signal treatment (Clipping Cap, preamps) can be optimized.
Pattern of channels (x,y) has some flexibility, Smaller in dense region close to beam.

Need to develop DAQ integration with CMS (based on HPTDC 25ps/bin module).
Reference timing system (Doug Wright and Jeff Gronberg, LLNL) good for < 2ps.